

Stochastic Modeling at Multiple Timescales



Hongyu Wu, Ph.D.

Hongyu.Wu@nrel.gov

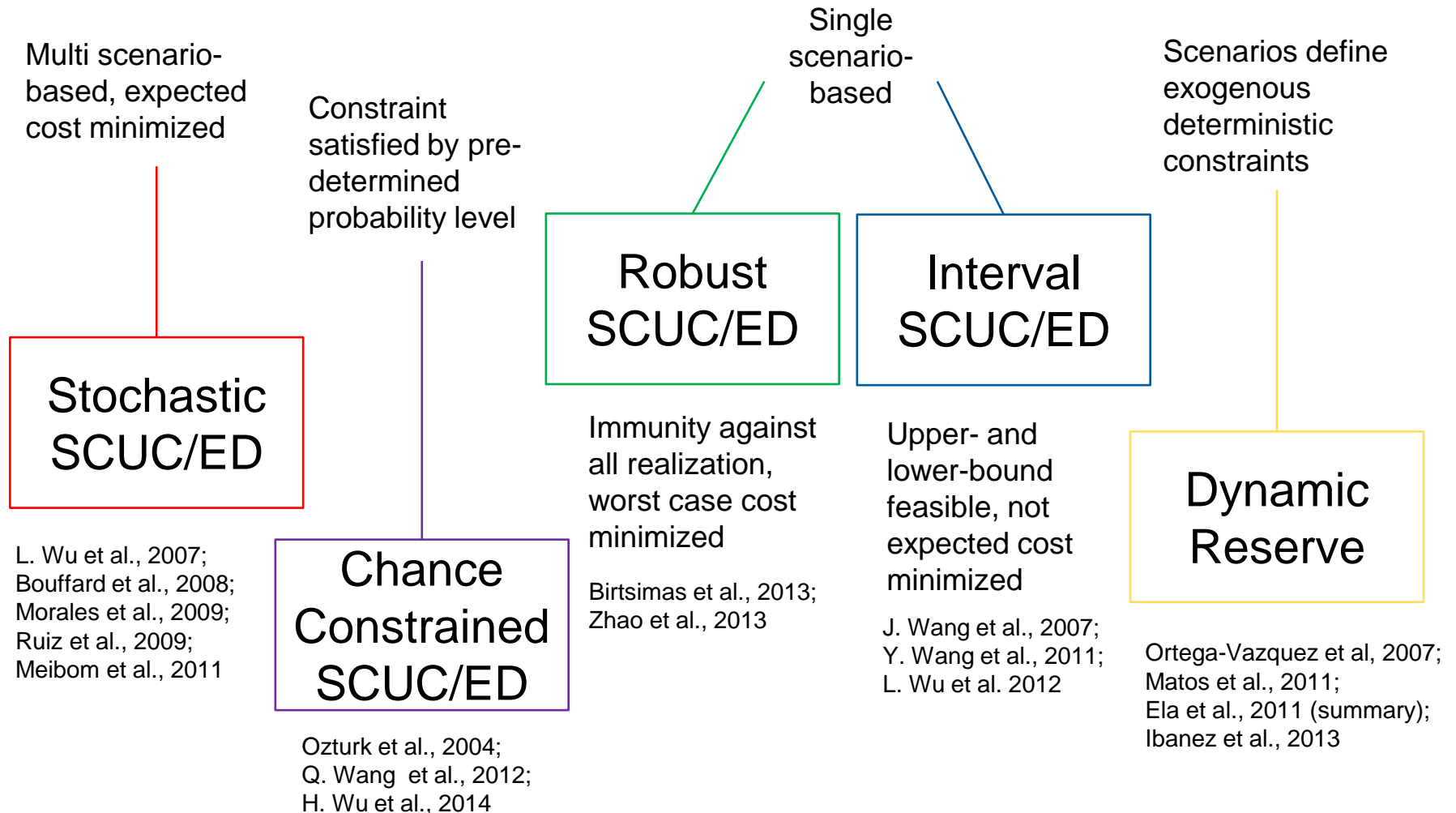
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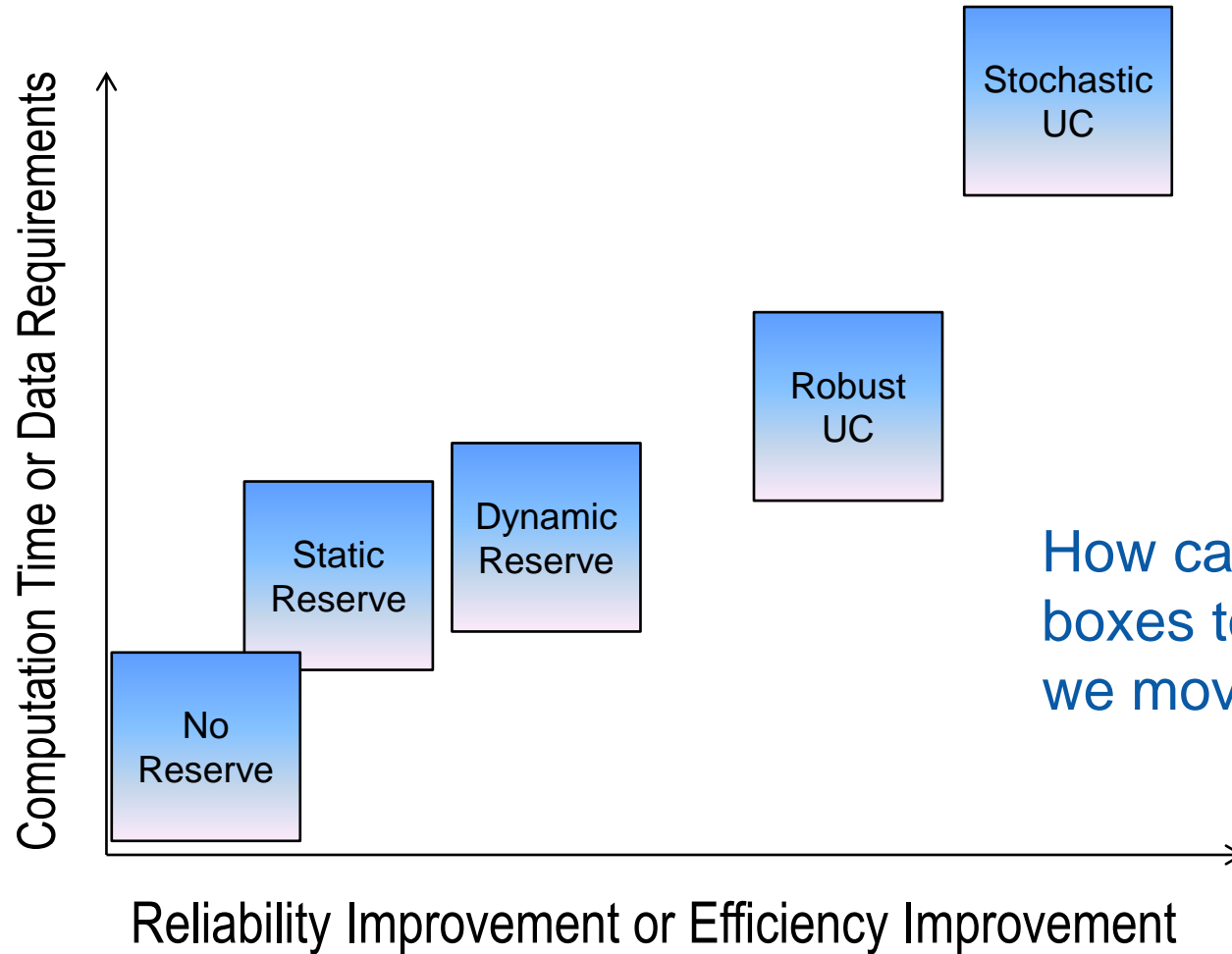
Outline

- **Terminology check and project overview**
- **Multiple timescale modeling framework**
 - **Stochastic model**
 - **Robust model**
- **Probabilistic Forecasts**
- **Future work**

Terminology Check



How to prepare for uncertainty?

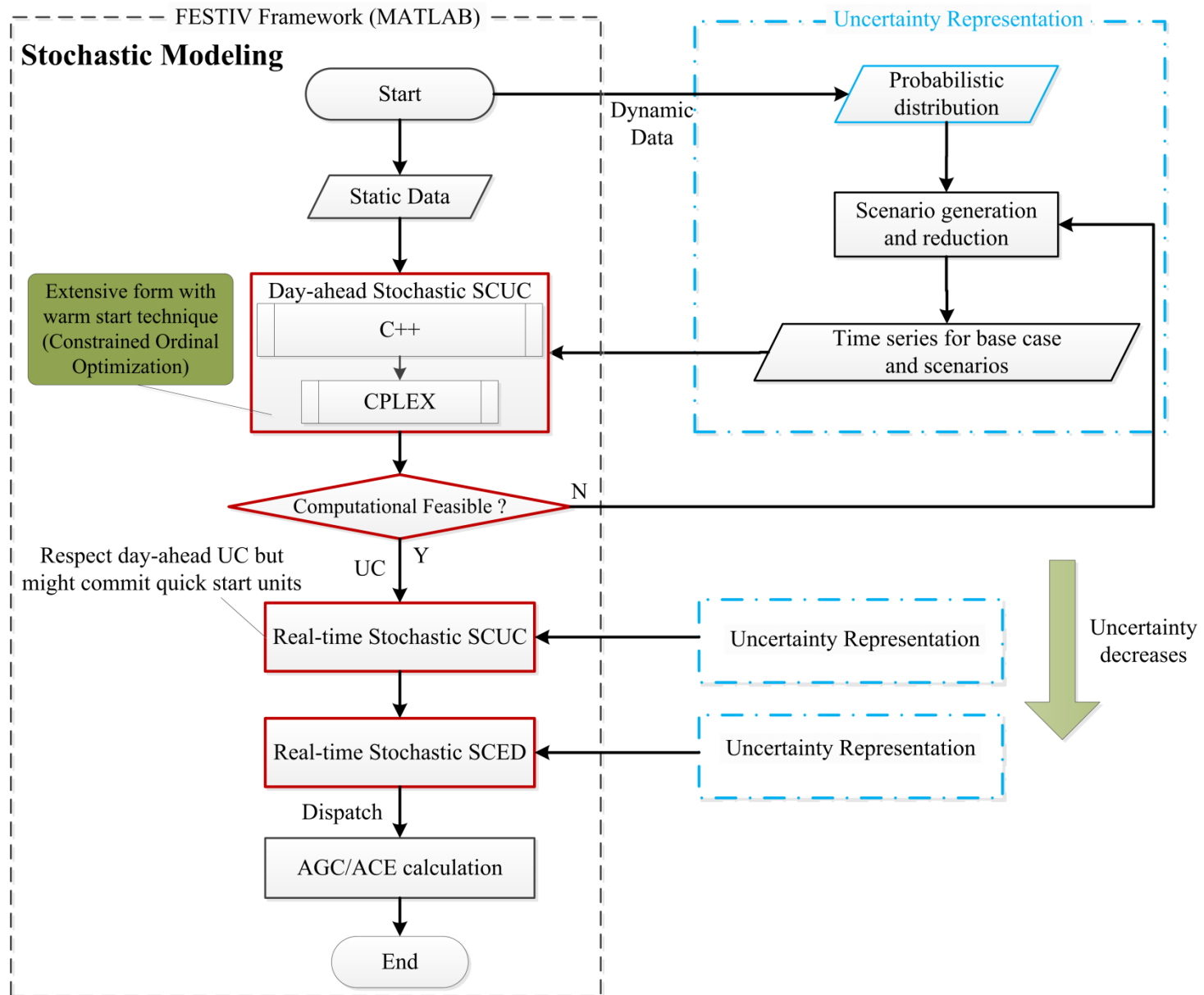


How can we move the boxes to the right? or can we move them down?

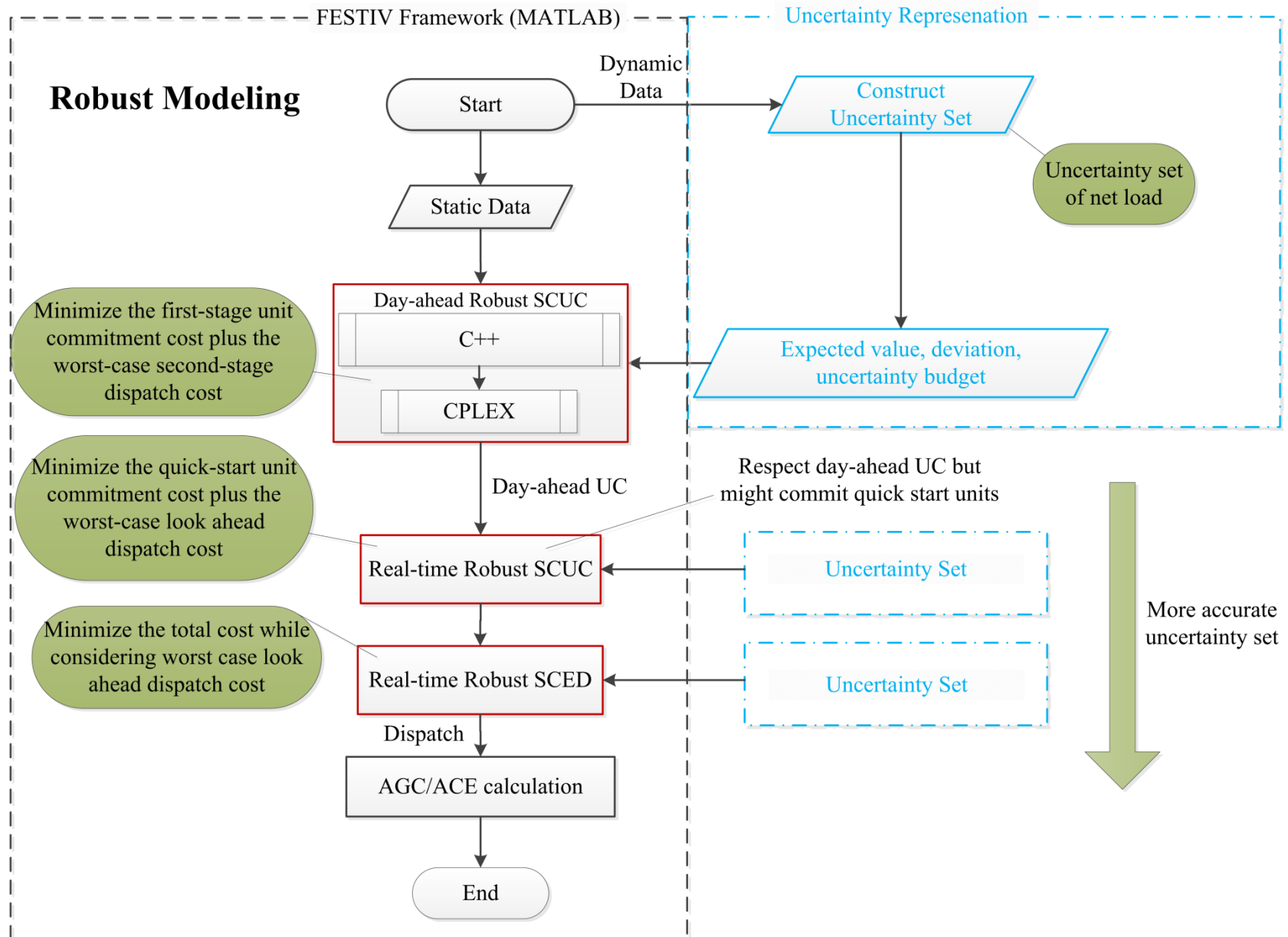
Project Goals

- renewable resource and load forecasting error characteristics representing probabilistic forecasts with correlations across time, space, and each other (e.g., load and solar)
- Stochastic model, operating at multiple time resolutions and time horizons
 - Merge with DASCUC, RTSCUC, RTSCED
- Robust model, operating at multiple time resolutions and time horizons
 - Merge with DASCUC, RTSCUC, RTSCED
- Understanding of how each strategy (along with intelligent dynamic reserve) impacts the system in terms of :
 - Production costs
 - Imbalance (improves reliability)
 - Incentive structure, i.e., how resources are paid to provide additional flexibility
 - Computation time

Multiple Timescale Stochastic Model



Multiple Timescale Robust Model



COO for Stochastic SCUC (Cont'd)

Scenario based (SB) method in terms of MCS is one of the major solutions of Stochastic SCUC

SB method Characteristics

- The accuracy of MCS is at best $1/(N)^{1/2}$
- A non-convex, NP-hard SCUC in each scenario
- Hard coupling constraints link all scenarios


**Multiplicative
Impacts !**

Drawbacks: Computationally infeasible when considering a large number of scenarios

COO for Stochastic SCUC (Cont'd)

Goal: finding good enough solutions with high probability instead of searching the best solution with certainty.

Two tenets:

- Ordinal Comparison
 - Goal Softening
- 
- Intuitively reasonable,
mathematically proven***
- Advantages
 - Saves computation efforts by at least one order of magnitude
 - Convergence rate of COO is exponential, which is much faster than $O(1/(N)^{1/2})$ of MCS

* Y. C. Ho, Q. Zhao, and Q. Jia, Ordinal optimization: Soft optimization for hard problems, New York: Springer, 2007.

COO for Stochastic SCUC (Cont'd)

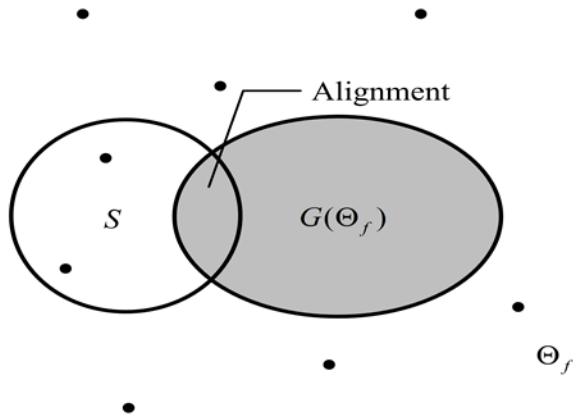
■ Generalized S-SCUC

$$\min_{\mathbf{I}, \mathbf{P}^s} J(\mathbf{I}, \mathbf{P}^s) = \min_{\mathbf{I}, \mathbf{P}^s} \lim_{NS \rightarrow \infty} \sum_{s=1}^{NS} \mu_s \cdot L(\mathbf{I}, \mathbf{P}^s, \xi^s)$$

$$s. t. \quad h(\mathbf{I}, \mathbf{P}^s) \leq 0,$$

$$\mathbf{I} \in \Theta,$$

■ Alignment Probability



$$\text{Prob}(|G(\Theta_f) \cap S| \geq k) \geq a$$

■ Feasibility Model

$$\sum_{i \in E_{1,t}} P_i^{\max} + \sum_{w \in E_{2,t}} P_{w,t}^{\text{f},\max} \geq D_t^s, \forall t, \forall s$$

$$\sum_{i \in E_{1,t}} P_i^{\min} \leq D_t^s, \forall t, \forall s$$

$$\sum_{n=1}^{k-1} (a_{l,i_n} - a_{l,i_k}) \bar{P}_{i_n} + \sum_{n=k+1}^N (a_{l,i_n} - a_{l,i_k}) \underline{P}_{i_n}$$

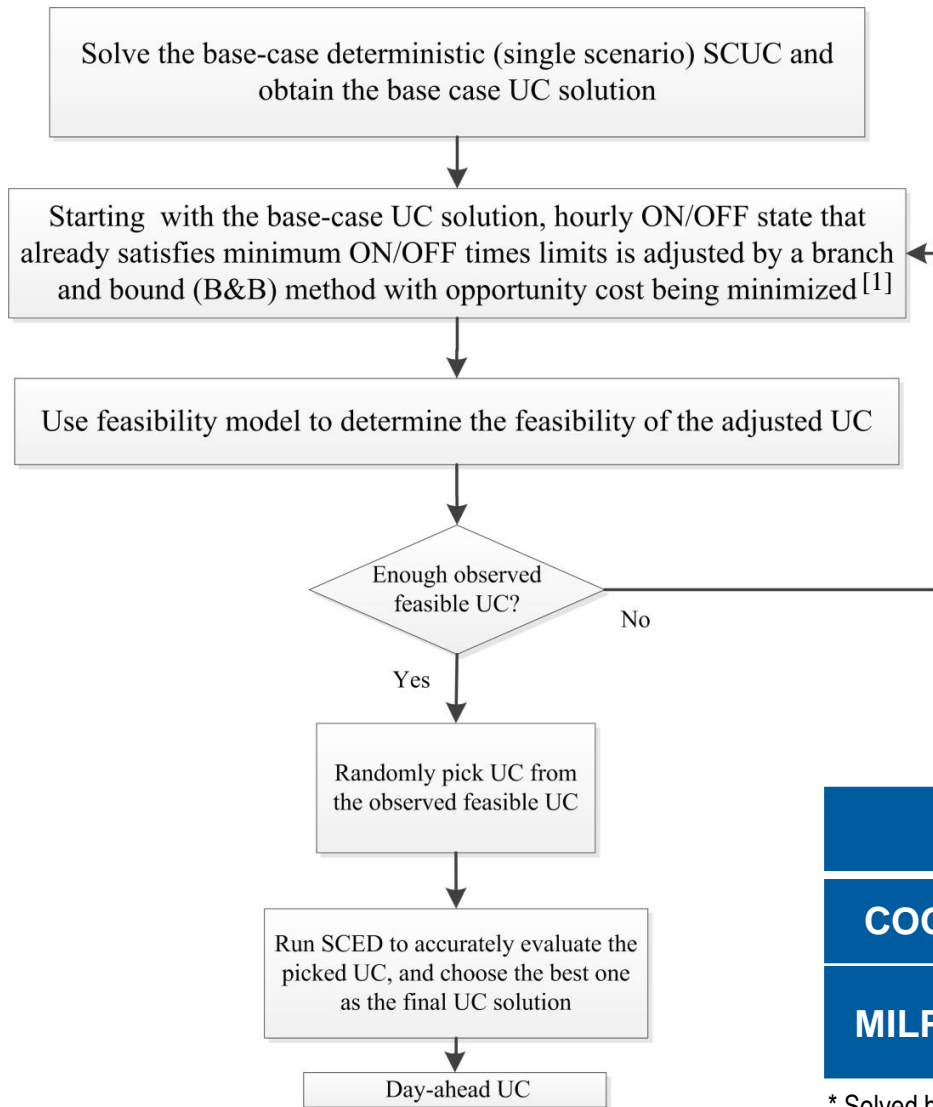
$$+ a_{l,i_k} D_t^s \leq B_{l,t}, \forall l, \forall t, \forall s$$

$$\text{Prob}(|G(\Theta_f) \cap S| \geq k)$$

■ BPFM

$$= \sum_{j=k}^{\min(g, S_N)} \sum_{i=0}^{S_N-j} \frac{\binom{g}{j} \binom{M-g}{S_N-i-j}}{\binom{M}{S_N-i}} \binom{S_N}{i} q^{S_N-i} (1-q)^i \geq a$$

COO for Stochastic SCUC



- ❑ Consider a wind penetration level of 21.7% in IEEE 118-bus system
- ❑ Uncertainties: forecast errors of wind speed and hourly load as well as random outages of generating units and transmission lines
- ❑ Compare the COO with the CPLEX solution with default settings for solving the extensive form with 185 scenarios

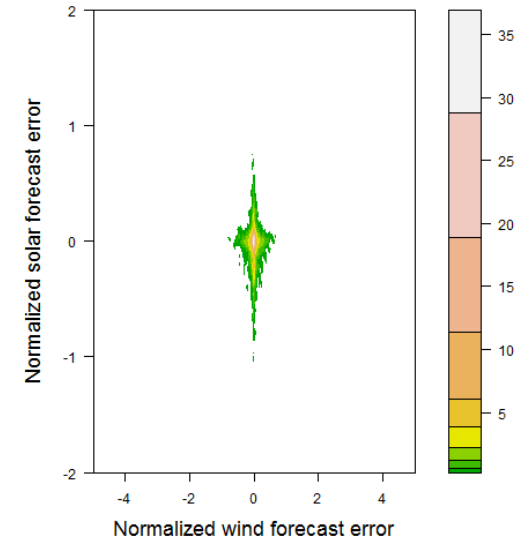
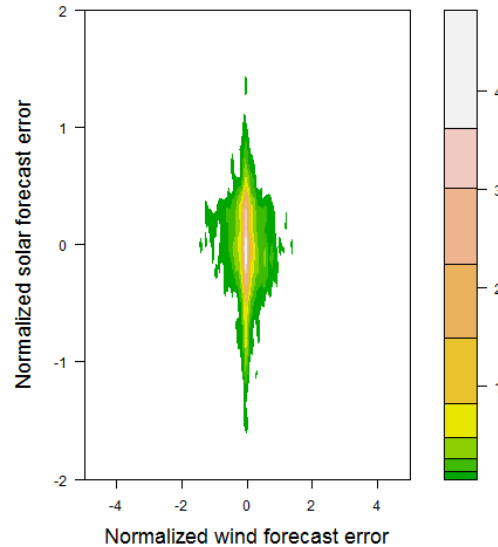
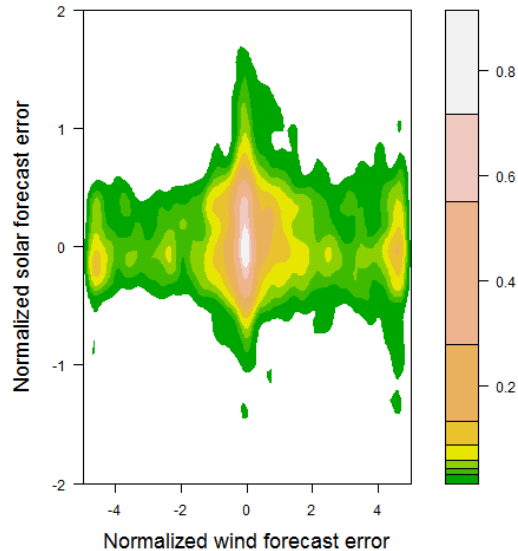
	Operation Cost (\$)	EENS (MWh)	CPU Time (s)
COO	1,431,840 ±65,330	6.11	1612
MILP*	1,437,110 ±162,760	6.03	47359

90% savings

* Solved by CPLEX with reduced 16 scenarios

[1] H. Wu, X. Guan, et al, "A systematic method for constructing feasible solution to SCUC problem with analytical feasibility conditions [J]," IEEE Trans. on Power Systems, vol. 27, no. 1, pp.526-534, Feb. 2012.

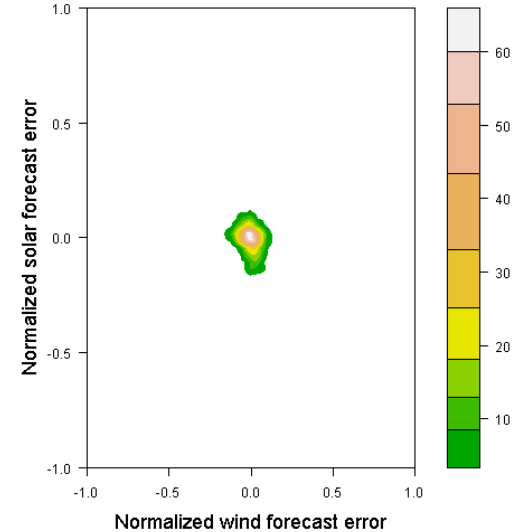
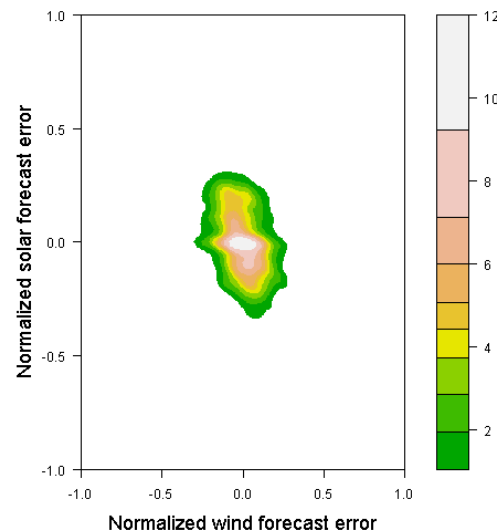
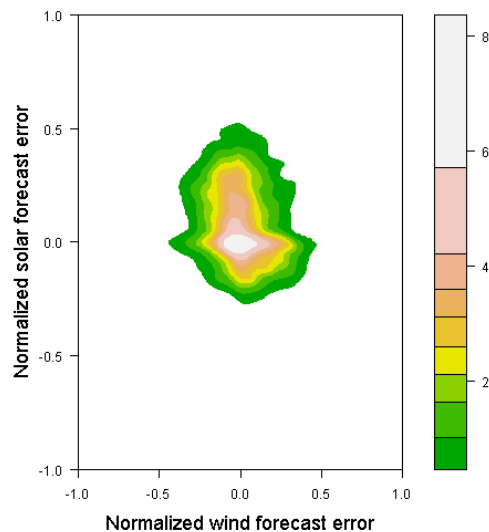
Forecast Errors of different time scales



(a) Day-ahead joint distribution

(b) Four-hour-ahead joint distribution

(c) One-hour-ahead joint distribution



Correlation Analysis of Different Timescales

Pearson's correlation coefficients¹

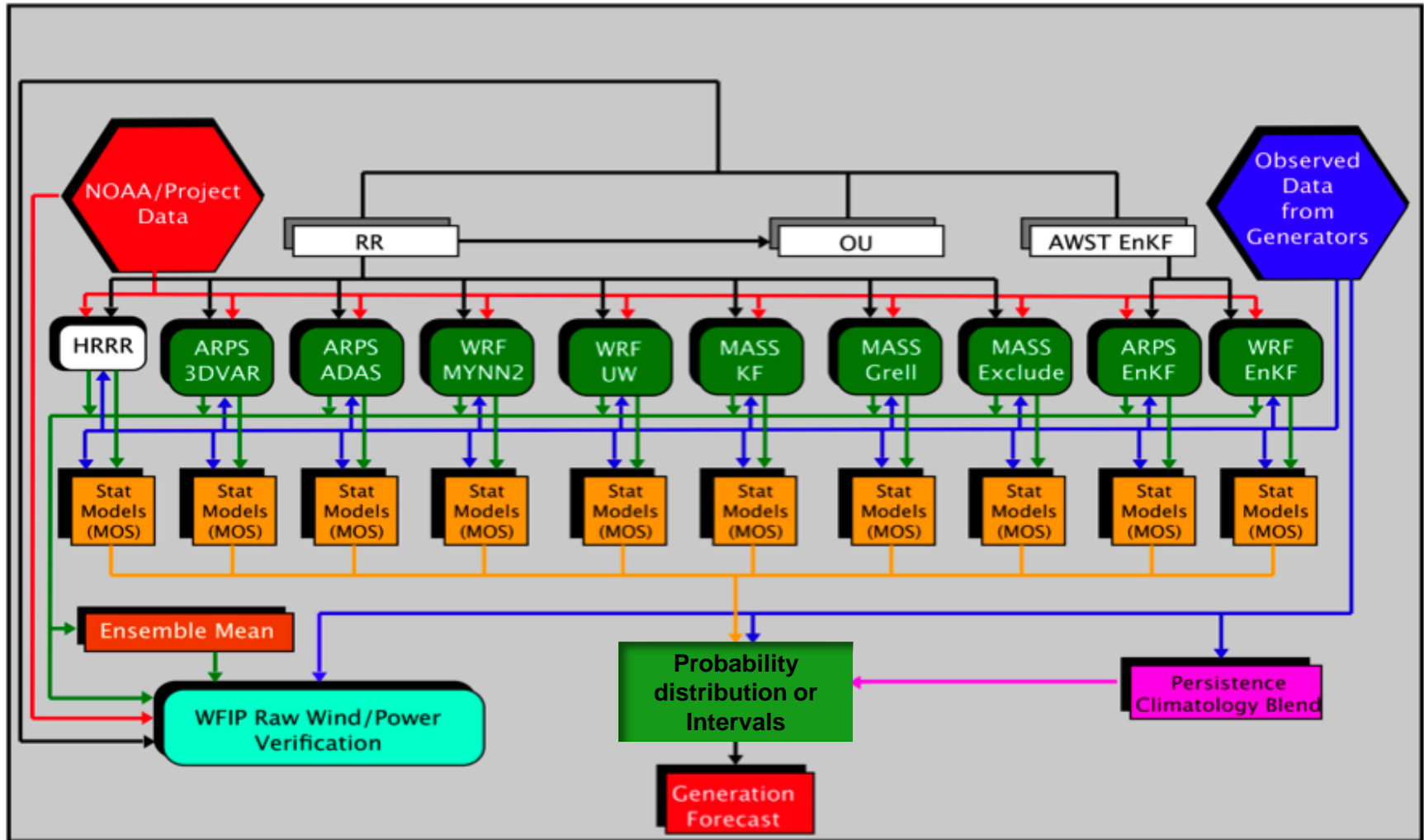
	Day-Ahead			Four-Hour-Ahead			One-Hour-Ahead		
	Year	Jan.	July	Year	Jan.	July	Year	Jan.	July
WWSIS*	-0.19	-0.21	-0.30	-0.34	-0.18	-0.63	-0.13	-0.06	-0.34

- Wind and solar generation forecast errors are **inversely correlated**
- **A larger inverse correlation would be preferable**, as a large positive wind forecasting error would be more likely to be offset by a negative solar forecasting error
- Our future work will investigate the impact of the inverse correlation on the reliability and efficiency of each model

* WWSIS: Western Wind and Solar Integration Study

1. J Zhang, BM Hodge, A. Florita, Joint probability distribution and correlation analysis of wind and solar power forecast errors in WWSIS, Journal of Energy Engineering, 2014

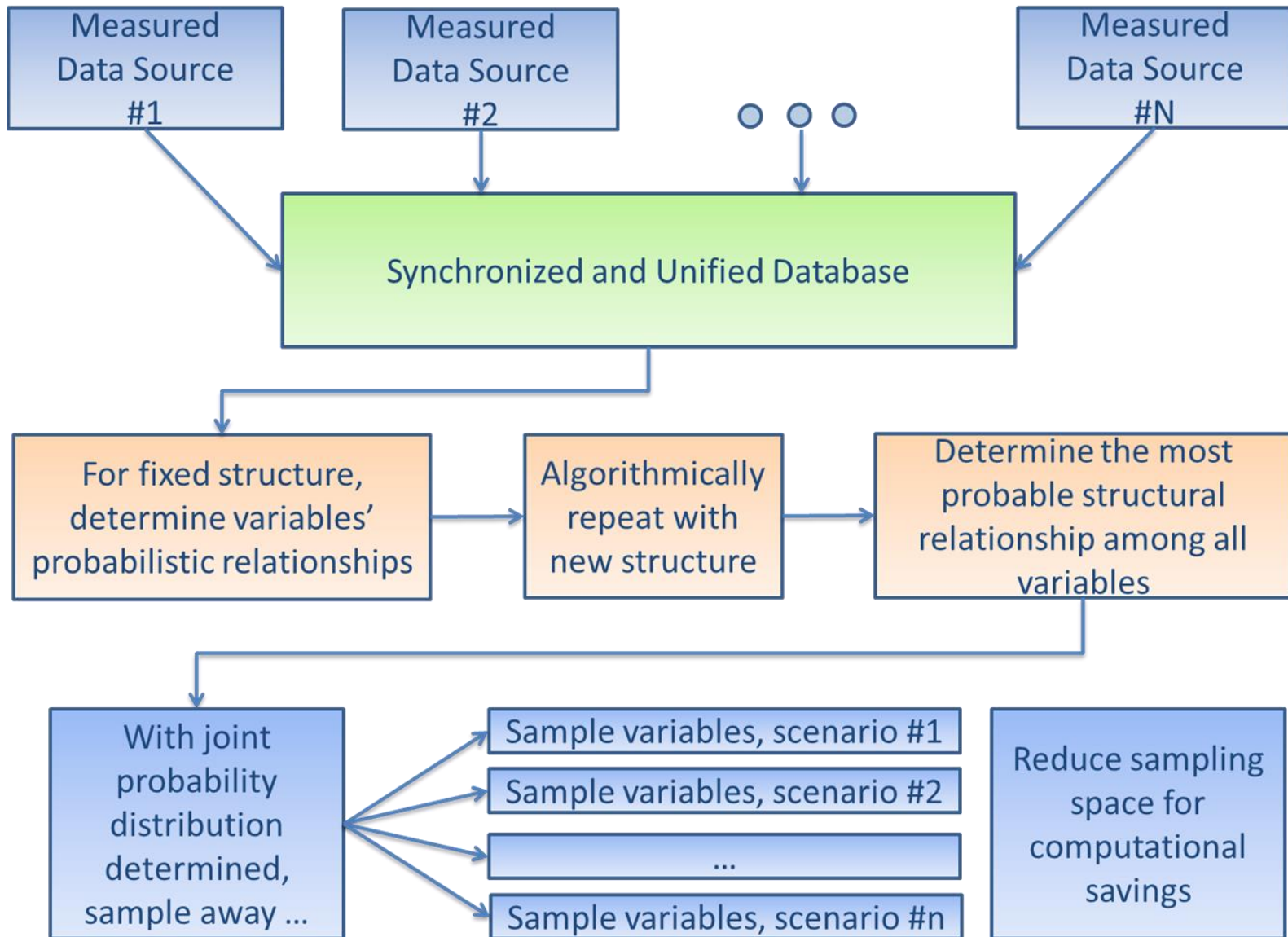
Wind Generation Forecast



Probabilistic wind generation forecasts for the next 6 hours with 15-minute time resolution

J Zhang, A Florita, BM Hodge, et al., Ramp forecasting performance from improved short-term wind power forecasting, IDETC/CIE 2014

Load Forecast



Future Work

- Direct comparison of SSCUC, RoSCUC, and Dynamic OR in terms of reliability (imbalance), efficiency (prod. cost), and incentive structure (profit)
- Integration into market designs
 - New advanced models schedule operating reserve inherently within model, without dual value for reserve constraint
 - DAM SCUC and Reliability SCUC interaction and evolution
 - Is it plausible for the ISO to receive probabilistic bids from market participants?
- Stochastic Energy (vs. Power) scheduling

Questions

Hongyu.Wu@nrel.gov

Erik.Ela@nrel.gov

Anthony.Florita@nrel.gov

Bri.Mathias.Hodge@nrel.gov

Jie.Zhang@nrel.gov

Ibrahim.Krad@nrel.gov

<http://www.nrel.gov/electricity/transmission>